

## TITLE OF THE INVENTION

[0001] Stimulation Electrode and Its Use

## BACKGROUND OF THE INVENTION

[0002] The invention relates to a stimulation electrode with an electrode surface which is at least partially covered with a coating of titanium nitride, wherein the titanium nitride has a larger surface on its side remote from the electrode surface than the region of the electrode surface covered with the titanium nitride. The invention further relates to the use of such an electrode.

[0003] Such stimulation electrodes are known from German published patent application DE 42 07 368 A1. The stimulation electrode disclosed there is provided with a porous coating, the surface of the porous coating being greater than the surface of the basic surface form of the coated electrode. Nitrides, carbides, carbonitrides or pure metals or alloys of the elements Au, Ag, Ir, Pt and also carbon are disclosed as coating materials. The disclosed stimulation electrode is used as a cardiac pacemaker or neuro-stimulation electrode.

[0004] Published U.S. patent application 2001/0002000 A1 discloses substrates of plastic, metals, etc., with a biocompatible coating, which is formed from amorphous titanium nitride. The applications of the substrates are in the field of cardiac pacemakers and electrodes.

[0005] European published patent applications EP 117 972 A, EP 116 280 A and EP 115 778 A disclose electrodes for medical applications, provided with porous layers of titanium nitride.

[0006] U.S. Patent 4,602,637 discloses a cardiac pacemaker system in which the passive electrode is coated, for example, with activated carbon or titanium nitride.

[0007] German published patent application DE 33 00 672 A1 discloses a cardiac pacemaker system with an electrode which has, for example, a coating of titanium nitride.

[0008] The publication, J. Riedmüller, A. Bolz, H. Rebling, M. Schaldach, "Improvement of Stimulation and Sensing Performance of Bipolar Pacemaker Leads", *Proceedings of the Annual International Conference of the IEEE/EMBS*, pp. 2364-2365 (1992), discloses that the use of titanium nitride layers with anodic polarization leads to the formation of oxide layers in the region of the electrode surface. While the physical properties of the titanium nitride are substantially unchanged in stimulation electrodes with a titanium nitride layer which is used as the cathode, this is not the case with use as an anode. The attack by OH<sup>-</sup> ions leads to the formation of oxide layers, which cause a rise of impedance and therewith also a rise of the threshold voltage. In Fig. 2 of this publication, an iridium-coated titanium electrode is placed opposite one coated with titanium nitride.

In anodic operation, the Helmholtz capacity of the titanium nitride-coated electrode falls very much faster than that of the iridium-coated electrode.

#### BRIEF SUMMARY OF THE INVENTION

[0009] The problem is now to provide stimulation electrodes with at least a partial titanium  
5 nitride coating, which have a sufficient lifetime in anodic operation.

[0010] The problem is solved in that the titanium nitride is covered with at least one oxidation  
protection layer on its side remote from the electrode surface, wherein at least the side of the  
oxidation protection layer facing toward the titanium nitride coating is substantially non-porous. By  
“substantially non-porous” is meant that at least the side of the oxidation protection layer facing the  
10 titanium nitride coating should be dense, although it will be understood that during manufacture  
unavoidable dislocations or pinholes affecting the imperviousness of the layer may occur, at least  
selectively. The use of an oxidation protection layer on the titanium nitride surface leads to the  
complete prevention or at least substantial slowing of the formation of oxide layers in the region of  
the stimulation electrode.

[0011] As materials for the stimulation electrode itself, titanium, gold, stainless steel, platinum,  
15 platinum-iridium alloys, particularly the alloy Pt90Ir10, and also carbon, are preferred.

[0012] It has been found advantageous when the at least one oxidation protection layer reduces  
the impedance of the stimulation electrode coated with titanium nitride, or else increases the  
impedance to a maximum value which is smaller than the impedance of the uncoated stimulation  
20 electrode.

[0013] It has furthermore been found advantageous when the at least one oxidation protection  
layer has a layer thickness in the range of about 100 nm – 5  $\mu$ m. Care must be taken that a sufficient  
oxidation protection action is attained and also that the surface structure of the titanium nitride is not  
substantially affected. Thus, the layer thickness is, to the extent possible, to be chosen so that the  
25 large surface of the titanium nitride is completely or largely retained. In particular, layer thicknesses  
of the oxidation protection layer in the range of about 100 nm – 2  $\mu$ m, ideally in a range of about  
500 nm to 2  $\mu$ m, have been found to be satisfactory.

[0014] It is particularly preferred that the oxidation protection layer be biocompatible. It is  
preferred that the at least one oxidation protection layer be formed of at least one of the elements  
30 iridium, platinum, gold or carbon, but pure platinum or iridium is preferred. It is particularly  
preferred to form the at least one oxidation protection layer of an oxide, a carbide, a nitride, or a  
polymer, where of course care must be taken that materials are used which reduce the impedance of

the stimulation electrode coated with titanium nitride, or else increase the impedance to a maximum value which is smaller than the impedance of the uncoated stimulation electrode.

[0015] In particular, it has been found to be satisfactory to use iridium oxide, particularly substoichiometric iridium oxide, as the oxidation protection layer on the titanium nitride.

5 [0016] The at least one oxidation protection layer is preferably formed by a PVD (physical vapor deposition) or CVD (chemical vapor deposition) process. However, formation by spraying, dipping, electrodeposition or a sol-gel process is also possible.

[0017] The use of such a stimulation electrode with a titanium nitride layer having an oxidation protection layer arranged thereon as a cardiac pacemaker electrode, neuro-stimulation electrode, or  
10 in another human implant is ideal. It is particularly advantageous to use the stimulation electrode as the anode.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0018] The foregoing summary, as well as the following detailed description of the invention, will be better understood when read in conjunction with the appended drawings. For the purpose of  
15 illustrating the invention, there is shown in the drawings an embodiment which is presently preferred. It should be understood, however, that the invention is not limited to the precise arrangements and instrumentalities shown. In the drawings:

[0019] Fig. 1 is a side view, partially in section, of a stimulation electrode having a titanium nitride layer and an oxidation protection layer according to one embodiment of the invention;

20 [0020] Fig. 1a is an enlarged diagram of the fragment A from Fig. 1.

#### DETAILED DESCRIPTION OF THE INVENTION

[0021] Fig. 1 shows the stimulation electrode 1. The stimulation electrode may have any shape besides that shown here. Thus, the stimulation electrode 1 can also be embodied in the form of a spiral wire. The electrode surface of the stimulation electrode 1 is partially covered with a coating 2  
25 of titanium nitride. The coating 2 of titanium nitride is here covered on its side remote from the electrode surface of the stimulation electrode 1 with a 1  $\mu$ m thick oxidation protection layer 3 of iridium.

[0022] Fig. 1a shows in detail the fragment A from Fig. 1 in the region of the coatings. It can be seen that the coating 2 of titanium nitride has, on its side remote from the electrode surface of the  
30 stimulation electrode 1, a surface which is larger than that of the region of the electrode surface covered with titanium nitride. That is, the surface of the titanium nitride coating 2 is uneven or textured, for example, in this embodiment having hills and valleys. The oxidation protection layer 3

covering the coating 2 of titanium nitride reproduces, to a large extent, the surface structure of the titanium nitride, so that the large surface of the coating 3 of titanium nitride remains completely or largely retained.

5 **[0023]** It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but it is intended to cover modifications within the spirit and scope of the present invention as defined by the appended claims.